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AN AERIAL RADIOLOGICAL SURVEY OF
**TECHNICAL AREAS 2, 21, AND 53
AND SURROUNDINGS**
LOS ALAMOS NATIONAL LABORATORY

LOS ALAMOS, NEW MEXICO

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ABSTRACT

An aerial radiological survey of the entire Los Alamos National Laboratory was flown in September 1982. The data from a part of the survey, Technical Areas 2, 21, and 53, are presented here along with pertinent data from an October 1975 survey of limited areas of Los Alamos. The data from Technical Area 15, another part of the survey, will be published in another report.

Contour maps of the gamma survey data show some Cs-137 activity in Los Alamos Canyon as well as in DP Canyon beside TA-21. Some Be-7, Sb-124, and Co-58 apparently exist in the canyon immediately below the Los Alamos Meson Physics Facility (LAMPF) ponds. Estimates of the Cs-137 inventory in the canyons range from 210 mCi to 1,270 mCi.

An exposure rate contour map at 1 meter above ground level (AGL) was constructed from the gamma data and overlaid on an aerial photograph and map of the area. The terrestrial exposure rates ranged from 6 μ R/h to about 18 μ R/h.

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1.0 INTRODUCTION

An aerial radiological survey of the entire Los Alamos National Laboratory and the adjacent area was conducted in September 1982. The survey was performed by EG&G Energy Measurements, Inc. (EG&G/EM) at the request of the U.S. Department of Energy (DOE).

The object of the survey was to measure the natural terrestrial gamma exposure rates as well as the location and intensity of anomalous, man-made gamma emitters. Gamma data from the NaI(Tl) detectors were reduced to exposure and concentration plots overlaid on aerial photographs of Los Alamos.

Because Los Alamos covers a large area, gamma maps of the entire area as well as subsections of the area have been produced. The subject of this report is the subsection around Technical Areas 2, 21, and 53. A map showing these locations, (Figure 1) depicts an area of 1,490 hectares (5.7 square miles).

2.0 DATA ACQUISITION

The entire Los Alamos area, including the area around TA-2, TA-21, and TA-53, was surveyed using a Messerschmitt-Bolkow-Blohm (MBB) BO-105 helicopter. Parallel flight lines were flown in east by southeast and west by northwest directions under the guidance of a microwave

ranging system (MRS). Two transponders on the ground (one at Mt. Cerro Piñon and one at Mt. Glorieta Baldy) and a master unit on the aircraft provided the pilot with a steering vector. Two passes through each of the major Los Alamos canyons were also flown, but not under the guidance of the MRS. The transponder signal generally could not reach the aircraft in the canyons. However, canyon position data were obtained from an on-board inertial navigation unit. In addition, the area from the airport to East Jemez Road was resurveyed (a mini survey) on 25 September 1982, a day when the High Energy Physics Facility was at low power. The airborne plume of 0.511-MeV gamma emitters (O-15, N-13, C-11) tended to mask this neighborhood when the facility was at normal operating level.

An outline of the survey parameters is given in Table 1.

3.0 DATA ANALYSIS

The gamma energy spectra, accumulated once each second, were interpreted for natural exposure rate at 1 meter AGL. (Appendix A contains a general description of how exposure rate is obtained from the total count rate.) The exposure rate was contoured and plotted on a photograph of this survey area (TAs 2, 21, and 53). The mini survey contours were adjusted to the large area survey contours to construct this map.

Table 1. Hardware, Flight, and Data Parameters

Aircraft	MBB BO-105 helicopter
Aircraft speed	37 m/s (120 ft/s)
Altitude	61 m (200 ft)
Survey line spacing	91 m (300 ft)
Survey line direction	East by Southeast ($\sim +102^\circ$)
Number of lines	30 on the contour maps
Gamma detectors	20, 12.7-cm $\times$ 5.1-cm NaI(Tl)
Data recording system	REDAR IV
Data recorded	Gamma spectra, atmospheric temperature and pressure, altitude and position values from the microwave transponders
Data acquisition rate	Once per second

FIGURE 1. LOCATION OF TECHNICAL AREAS 2, 21, AND 53

The gamma spectra were also examined for any man-made isotopes that might exist in the Los Alamos environment (Appendix A). These data were contoured and fitted to a map of the area.

The principal man-made isotope found in the soil outside the technical areas, Cs-137, was also extracted from the gamma spectra and contoured. In addition, the Cs-137 data from the 1975 aerial survey were included on this map.

Finally, an inventory of the Cs-137, found mainly in Los Alamos and DP Canyons, was computed.

4.0 RESULTS

The primary results of the aerial survey are illustrated on three contour maps: the man-made gross count (MMGC) map, the Cs-137 map, and the exposure map. The purpose is to show where and how much anomalous radioactivity occurs. Some interpretation of each map is given in the following sections.

4.1 Man-Made Gross Count Contours

The man-made gross count maps (Figures 2a, 2b, 2c, and 2d) display the intensity and location of man-made isotopes with gamma energies between 40 keV and 1,400 keV. The algorithm for MMGC is given in Appendix A. Contour levels are labeled in counts per second (cps). No effort has been made to transform these levels to source strength, because most of the anomalous regions are quite complex, and the MMGC does not readily lend itself to the computation of activity.

Gamma spectra were extracted from areas where MMGC was significant. The gamma spectrum from TA-2 (Figure 3) shows the presence of Na-24 and Cs-137 as well as the possibility of Co-60. Ar-41 also exists over TA-2, as indicated from spectra taken on different dates, but this is not clear in the mini survey spectra.

Cesium-137 appears to exist in TA-21 and is strong in DP Canyon beside TA-21 (Figures 4 and 5).

Isotopes visible in the LAMPF area include Bremsstrahlung over the west end (Figure 6) and Co-58 and Co-60 over the target area (Figure 7). The gamma spectrum is complex over the LAMPF ponds and in the canyon below the ponds (Figures

8 and 9). The isotopes Na-24, Be-7, Sb-124, and Co-60 seem clearly indicated; V-48 and Co-56 are possible. The poor resolution of the NaI detector makes identification of isotopes somewhat difficult.

Los Alamos Canyon contains detectable Cs-137 over much of its length from DP Canyon to Highway 4 (Figures 10, 11, and 12). The next section treats Cs-137 in more detail.

Some caveats on the integrity of the MMGC map include: 1) most of these particular data were taken on Saturday, 25 September 1982 when the reactors were shut down and LAMPF was operating at low power, so neither Ar-41 nor the 511-keV gammas were generally observable; 2) the MMGC was not a perfect algorithm for the reactor area or the LAMPF ponds because the high energy Na-24 gammas are counted in the background energy window, causing some loss in sensitivity and some distortion of the contour; and 3) the minimum detectability of the MMGC algorithm varies from isotope to isotope and is finite, so some anomalous areas do not appear on this map.

4.2 Cesium-137 Contours

The Cs-137 contour maps (Figures 13a, 13b, 13c, and 13d) show this isotope distributed outside the technical area confines. The contours around TA-2 may be perturbed by Na-24 and other isotopes in this technical area.

A small amount of Cs-137 appears 800 ft south-east of TA-2 as shown in the gamma energy spectrum of Figure 14.

Most of the Cs-137 occurs in the canyon (DP Canyon) beside TA-21 and in Los Alamos Canyon. An inventory estimate for Cs-137 in both DP Canyon and Los Alamos Canyon is given in Table 2. The sensitivity of the aerial system to Cs-137 is given in Table 3. The method for computing sensitivity is given in Appendix B, and the inventory computation is described in Appendix C. From the table, one might expect the total Cs-137 inventory in DP Canyon and Los Alamos Canyon to range from approximately 200 to 1,300 mCi.

Some areas of Cs-137 activity were detected in Los Alamos Canyon during the 1975 survey.

Table 2. Cesium-137 Inventory Estimates			
α^* (cm ⁻¹)	millicuries		
	DP Canyon	Los Alamos Canyon	Total
1.0	120	90	210
0.1	290	215	505
0.03	730	540	1,270

* Vertical concentration parameter

Table 3. Photopeak Sensitivity to Cesium-137		
α^* (cm ⁻¹)	S_v^0 (pCi/cm ³ · cps)	S_A (μCi/m ² · cps)
1.0	0.186	0.00186
0.3	0.077	0.00257
0.1	0.045	0.00450
0.03	0.034	0.0113
0.01	0.030	0.0300

* Vertical concentration parameter in $C = C_0 \exp(-\alpha z)$

These are annotated on the cesium contour map in a color different from the 1982 contours. The Cs-137 minimum detectable activity (MDA) for the 1975 survey was about 0.2 μCi/m² and is less than the 0.4 μCi/m² for the 1982 survey. The 1975 contours enclose about 0.2 μCi/m² or more.

Though the 1975 canyon data was taken at a lower altitude with a larger detector set than the 1982 data, the 1975 system used visual navigation in the canyons and strip chart recorders to indicate the presence of Cs-137 to the operator. The operator then marked the spot on an aerial photo of the area. In addition, only two lines were flown through Los Alamos Canyon in 1975, whereas in 1982 both canyon lines and a system of parallel lines were flown over the area. Therefore, there were more data and there was better spatial resolution in 1982 than in 1975.

It is reasonable to conclude, then, that there was Cs-137 in Los Alamos Canyon in 1975 at the locations shown at levels greater than 0.2 μCi/m².

Furthermore, the total inventory was probably less in 1975 than in 1982.

4.3 The Natural Background Exposure Rate

The exposure rates at 1 meter due to natural terrestrial gammas only are shown in Figures 15a, 15b, 15c, and 15d. Only that fraction of the gamma energy spectrum from 1,400 keV to 3,026 keV was used in order to exclude the Cs-137 and other man-made isotopes from the map. Those areas where Na-24 was present are labeled on the map because these isotopes interfere with the natural exposure measurement. Appendix A treats the exposure measurement and computation in more detail.

The exposure rate map shows a lower natural exposure rate on the plateau tops (6 to 10 μR/h) than in the canyons (10 to 15 μR/h). This may be due to the canyon geometry where average distance from the detector to the soil surface is less than for the flat surface used in the gamma system calibration.

FIGURE 2a. CONTOUR MAP OF MAN-MADE GROSS COUNT IN TECHNICAL AREAS 2, 21, AND 53—ENTIRE AREA

FIGURE 2b. CONTOUR MAP OF MAN-MADE GROSS COUNT IN TECHNICAL AREAS 2, 21, AND 53—WESTERN PORTION

FIGURE 2d. CONTOUR MAP OF MAN

spectrum, the result of Equation 3 could be increased over the constant value. This is routinely applied in the data reduction software when a search is made for spectral

After the value of the constant, C , is determined over a natural area, Equation 3 is generally used in another form:

FIGURE 3. GAMMA ENERGY SPECTRUM OVER TA-2

FIGURE 5. GAMMA ENERGY SPECTRUM IN DP CANYON BESIDE TA-21

FIGURE 4. GAMMA ENERGY SPECTRUM OVER TA-21

FIGURE 6. GAMMA ENERGY SPECTRUM OVER THE INJECTOR OF LAMPF

FIGURE 7. GAMMA ENERGY SPECTRUM NEAR TARGET AREA OF LAMPF

FIGURE 9. GAMMA ENERGY SPECTRUM OVER THE CANYON BELOW LAMPF PONDS

FIGURE 8. GAMMA ENERGY SPECTRUM OVER LAMPF PONDS

FIGURE 10. GAMMA ENERGY SPECTRUM OVER LOS ALAMOS CANYON AT DP CANYON ENTRANCE

FIGURE 11. GAMMA ENERGY SPECTRUM OVER LOS ALAMOS CANYON, 4,500 FT EAST OF ENTRANCE TO DP CANYON

FIGURE 12. GAMMA ENERGY SPECTRUM OVER LOS ALAMOS CANYON, 8,100 FT EAST OF ENTRANCE TO DP CANYON

FIGURE 13b. CONTOUR MAP OF Cs-137 IN TECHNICAL AREAS 2, 21, AND 53—WESTERN PORTION

FIGURE 13c. CONTOUR MAP OF Cs-137 IN TECHNICAL AREAS 2, 21, AND 53—CENTRAL PORTION.
NOTE: The level inside the 1975 contour is greater than $0.2 \mu\text{Ci}/\text{m}^2$.

FIGURE 13d. CONTOUR MAP OF Cs-137 IN TECHNICAL AREAS 2, 21, AND 53—EASTERN PORTION

FIGURE 14. GAMMA ENERGY SPECTRUM, 800 FT
SOUTHEAST OF TA-2

FIGURE 15a. CONTOUR MAP OF NATURAL TERRESTRIAL EXPOSURE RATE OVER TECHNICAL AREAS 2, 21, AND 53—
ENTIRE AREA

FIGURE 15b. CONTOUR MAP OF NATURAL TERRESTRIAL EXPOSURE RATE OVER TECHNICAL AREAS 2, 21, AND 53—WESTERN PORTION

FIGURE 15c. CONTOUR MAP OF NATURAL TERRESTRIAL EXPOSURE RATE OVER TECHNICAL AREAS 2, 21, AND 53—CENTRAL PORTION

APPENDIX A GENERAL DATA ANALYSIS

A few useful methods to treat gamma energy spectra as measured by NaI(Tl) are discussed below.

GROSS COUNT RATE

The gross count rate (GC) is defined as the integral count in the energy spectrum between 38 keV and 3,026 keV.

$$GC = \sum_{E=38 \text{ keV}}^{3,026 \text{ keV}} \text{Energy Spectrum} \quad (1)$$

This integral includes all the natural isotope gammas from K-40, U-238, and Th-232 (KUT, the major terrestrial, natural gamma emitters). Other natural contributors to this integral are cosmic rays, aircraft background, and airborne radon daughters.

The response versus altitude of the aerial system to terrestrial gammas has been measured over a documented test line near Las Vegas, Nevada, for which the concentrations of KUT and the 1-meter exposure rates have been measured separately. From this calibration, the terrestrial gross count rate has been associated with the 1-meter exposure rate in microroentgens per hour ($\mu\text{R/h}$) for natural radioactivity. The conversion equation is:

$$ER(1 \text{ m}) = \frac{[GC(A) - B]}{1,324} \cdot e^{0.001957A} \quad (2)$$

where

$ER(1 \text{ m})$ = exposure rate extrapolated to 1 m AGL ($\mu\text{R/h}$)

A = altitude in feet

$GC(A)$ = gross count rate at altitude A (cps)

B = cosmic, aircraft, and radon background (cps)

The gross count has been used for many years in the aerial system as a measure of exposure. Its simplicity yields a rapid assessment of the gamma environment.

When low energy ($<1,400$ keV) man-made gammas are present, an estimate of the natural

exposure may be made by summing the counts in the energy window above 1,400 keV and multiplying this sum by the low energy to high energy ratio obtained from a "natural" area. This high energy fraction of the spectrum still contains some gammas from all the natural isotopes, so little information is lost.

The cosmic and aircraft components of Equation 2 have been determined from numerous data over water when airborne radon is low. The total value of B in Equation 2 is obtained by flying a test line (near a survey site) at two altitudes or more, from which the value of B may be determined assuming the altitude coefficient is known and the airborne radon is uniform.

Anomalous or non-natural gamma sources are found from increases in the gross count rate over the natural count rates. However, subtle anomalies are difficult to find using the gross count rate in areas where its magnitude is variable due to, for example, geologic or ground cover changes. Differential energy data reduction methods, as discussed in the next section, are used to increase the aerial system's sensitivity to anomalous gamma emitters.

SPECTRAL WINDOWS

The aerial system produces a gamma energy spectrum each second from which the GC is computed. Generally, the ratio of natural components in any two integral sections (windows) of the energy spectrum will remain nearly constant in any given area:

$$\sum_{E=a}^b ES / \sum_{E=b}^c ES = \text{Constant} = K \quad (3)$$

where

ES = energy spectrum

E = energy

$c > b > a$

If the window, a - b , is placed where gamma rays from a man-made emitter would occur in the

spectrum, the result of Equation 3 could be expected to increase over the constant value. This equation is routinely applied in the data reduction software when a search is made for specific isotopes.

After the value of the constant, K , has been determined over a natural area, Equation 3 is generally used in another form:

$$S = \sum_{E=a}^b ES - K \sum_{E=b}^c ES \quad (4)$$

The net signal, S , is zero unless anomalous gamma rays are measured in the window defined by a and b .

Equation 4 is used to locate specific isotopes by setting a and b to enclose the photopeak of the particular gamma from the isotope. For the general case when all man-made isotopes are sought, a , b , and c are set at 38 keV, 1,394 keV, and 3,026 keV respectively. Because most long-lived man-made isotopes emit gammas in this energy range (38 keV to 1,394 keV), Equation 4 becomes a general search tool.

APPENDIX B

AERIAL DETECTOR SENSITIVITIES TO UNCOLLIDED TERRESTRIAL GAMMA RAYS

The photopeak counts registered by the airborne detectors can be accurately related to the concentrations of nuclides producing these photopeaks if some simplifying assumptions are made regarding the form of the distributions in the soil.

The assumptions made here are:

1. Distribution is infinite in extent in the lateral direction.
2. Distribution decreases exponentially with depth in the vertical direction.

$$C(z) = C_0 e^{-\alpha z} = \alpha S_A e^{-\alpha z} \quad \gamma/\text{cm}^3 \cdot \text{s} \quad (1)$$

where

C_0 = volume concentration in an infinitesimal element at the surface of the ground

S_A = total concentration per unit lateral area

α = reciprocal of relaxation depth

z = depth in soil

The factor that converts photopeak count rate to C_0 and αS_A can be written:

$$S_v^0 = \frac{1}{X} \quad \gamma/\text{cm}^3 \cdot \text{s} \cdot \text{cps} \quad (2)$$

where

$$X = \frac{A_0}{2} \int_0^{90^\circ} \frac{R(\theta) e^{-\mu_a h \sec \theta} \tan \theta d\theta}{\alpha + \rho \mu_R \sec \theta}$$

A_0 = detector effective area for mono-energetic gamma total absorption in the detector for fluence perpendicular to the ground surface, cm^2

$R(\theta)$ = relative effective area versus the angle, θ , measured from the ground perpendicular to the pod

μ_a = the air mass attenuation coefficient for the gamma energy in question, cm^2/g

μ_R = the soil mass attenuation coefficient for the gamma energy in question, cm^2/g

h = the detector (aircraft) altitudes in units of air thickness, g/cm^2

ρ = soil density, g/cm^3

In practice, the effective area, A_0 , is measured with known point sources of different energies. The angular factor, $R(\theta)$, is measured and approximated with unity, cosine θ , or a linear combination of these to fit an angular response at a given gamma energy.

Aerial measurements are often compared with the average concentration per unit mass in a plug of the top few inches of the soil. If this plug is of area, A , in the lateral direction and extends to a depth, z , in the vertical direction, then the total activity in the plug is:

$$S = C_0 A \int_0^z e^{-\alpha x} dx = \frac{C_0 A}{\alpha} [1 - e^{-\alpha z}] \quad (3)$$

Since the mass of the plug is given by $M = Az\rho$, the average concentration per unit mass is:

$$\frac{S}{M} = \frac{C_0}{\alpha z \rho} [1 - e^{-\alpha z}] = \frac{S_A}{z \rho} [1 - e^{-\alpha z}] \quad (4)$$

This equation relates the measured value of S/M to C_0 and S_A . Measurements of C_0 and S_A determined from the soil samples can be directly compared with those from aerial data

APPENDIX C

RADIOACTIVE INVENTORY COMPUTATION

The EG&G/EM aerial systems gather and compute enough information to estimate a radioactive inventory above the minimum detectable activity in soil. The information used is:

1. A geometric and radiometric scaled isopleth map of the area
2. The mean count rate above background in each isopleth interval
3. The conversion from count rate to a specific isotope and concentration distribution in the soil

The area enclosed by each isopleth interval is measured with a suitably fine grid paper and multiplied by the conversion coefficient ($\mu\text{Ci}/\text{m}^2 \cdot \text{cps}$). The sum of all these computations for all the contour intervals yields the inventory. Where the concentration distribution (α) in the Equation $C = C_0 \exp(-\alpha z)$ is not well known, a range of inventories may be computed from different α values.

The inventory computation was also done as part of the contouring computer routine. The number of events in the interval and the mean count rate are easily obtained; the product of these factors, the area per event, and the conversion coefficient yields values close to those obtained manually.

APPENDIX D

UNCERTAINTIES IN MEASUREMENT AND INTERPRETATION

A number of uncertainties may contribute to misinterpretation of aerial gamma data listed in the contour map or tables of sensitivity and inventory. The sources of uncertainty are 1) contour broadening, 2) basic calibration uncertainty, and 3) airborne gamma emitters.

CONTOUR BROADENING

Contours (or isopleths) are computed from a linear extrapolation to a given magnitude between neighboring, actual data points. One might expect some contour distortion from the finite distance (about 100 ft) over which each data point is collected, but this uncertainty is small compared to that due to source detection, both before and after the detector arrives over the source. Thus, a point source on the ground will appear as a set of concentric circular isopleths or contours centered on a point source. The diameter of the circular contours will depend on the gamma energy of the source, the angular response of the detector, and the intensity of the source as well as the minimum detectable activity of the detection system. The area enclosed by any contour, then, will be enlarged or reduced depending on whether that area contains more or less activity than its surroundings. The aerial measuring system does not have an automated computing method that will convert aerial intensity/position data to source distribution. Rather, informed interpretations of a contour map should be made by technical people.

CALIBRATION UNCERTAINTY

The sensitivity of the aerial gamma system to monoenergetic sources has been measured versus angle in the laboratory. The extrapolation of an aerial photopeak count rate to a source concentration in or on the ground is computed. This method has been verified many times by flying the aerial system over known sources. The uncertainty

in such monoenergetic source measurements is 10% or less of the source value.

The sensitivity of the aerial system to natural elements (K-40, U-238 and progeny, and Th-232 and progeny) is checked several times each year from flights at several altitudes over a documented test line beside Lake Mead. The test line has been documented by 1) counting many soil samples, 2) *in situ* NaI(Tl) detector measurements, 3) *in situ* high purity germanium detector measurements and 4) ion chamber measurements in a gridded configuration.

The aerial total count rate versus altitude yields a curve to extrapolate an aerial measurement to the ground. The uncertainty of the exposure measurement derived from these data is $\pm 7\%$ of the exposure due to KUT (K-40, U-238, and Th-232).

AIRBORNE GAMMA EMITTERS

Radon (Rn-222) daughters are a significant contribution to the gamma count rates measured by the aerial system. Total count rates from Rn-222 vary from zero to perhaps 2,000 cps. This contribution, including that from cosmic rays and aircraft materials, is measured separately for each aircraft flight. A pass over a large body of water (if nearby) is made, or a dual altitude method over a test line is used to compute the total of radon plus cosmic plus aircraft background. The water contains no activity (in general), so the background contributions to the gamma count rate are measured directly. The dual altitude method yields two equations in two unknowns (the terrestrial count rate and the background count rate) and is a less preferable method than using "over water" measurements. The vertical distribution of the radon concentration may be the largest uncertainty in the dual altitude method, and the count rate uncertainty may be as large as 500 cps ($\sim 0.5 \mu\text{R/h}$) in terms of terrestrial exposure.

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